Mercury and Sulfur Cycling in the Great Salt Lake

September 25, 2008

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Great Salt Lake Background

- **Geography**
  - **2nd saltiest lake on Earth**
  - **4th largest terminal lake**
- **Environment**
  - **Extremely high sulfate concentration (10-20 g/L)**
  - **High [metal]**
- **Ecology**
  - **Vital stop-over for migratory birds**
  - **Brine shrimp & flies; Diatoms**

Microbial Alchemy

Following modification of Paracelsus to ancient Arabic ideas, the basis of matter was the alchemical trinity of principles-- salt, sulfur and mercury.

Salt was the principle of fixity (non-action) and incombustibility; mercury was the principle of fusibility (ability to melt and flow) and volatility; and sulfur was the principle of inflammability.

Microbial Alchemy

What happens when we have high doses of mercury, salt and sulfur?

"The dose makes the poison."

-Paracelsus

Sulfur

Source	$[SO_4^{2-}]$*	Reduction Rates
Fresh water	0.003 g/L	20-200 nmol $g^{-1}d^{-1}$
Sea water	0.9 g/L	100-300 nmol $g^{-1}d^{-1}$
Hypersaline	10-48.0 g/L	400-6,200 nmol $g^{-1}d^{-1}$

*10,000-fold difference in $[SO_4]$

(from Oren, 2002)

Great Salt Lake: More than meets the nose

Wednesday, November 5, 2003 Posted: 12:00 PM EST (1700 GMT)

SALT LAKE CITY, Utah (AP) -- Famed western writer Wallace Stegner called it "a desert of water in a desert of salt and mud and rock" -- an apt description for Utah's dead sea.

Only brine shrimp, which are less than a half-inch long, some bacteria and algae can survive in its waters, which are three to five times saltier than the ocean. But everyone gets a whiff when stiff winds blow the lake's peculiar odor -- known affectionately as "lake stink" -- into the Salt Lake valley.

For adventurers who can look past their nose, this desert of water -- much like the desert playa it spreads across -- is desolately beautiful. It spreads across 1,200 square miles and is home to

Full-grown bison and calves cross a road to another pasture on Antelope Island, the Great Salt Lake's largest island.

Story Tools
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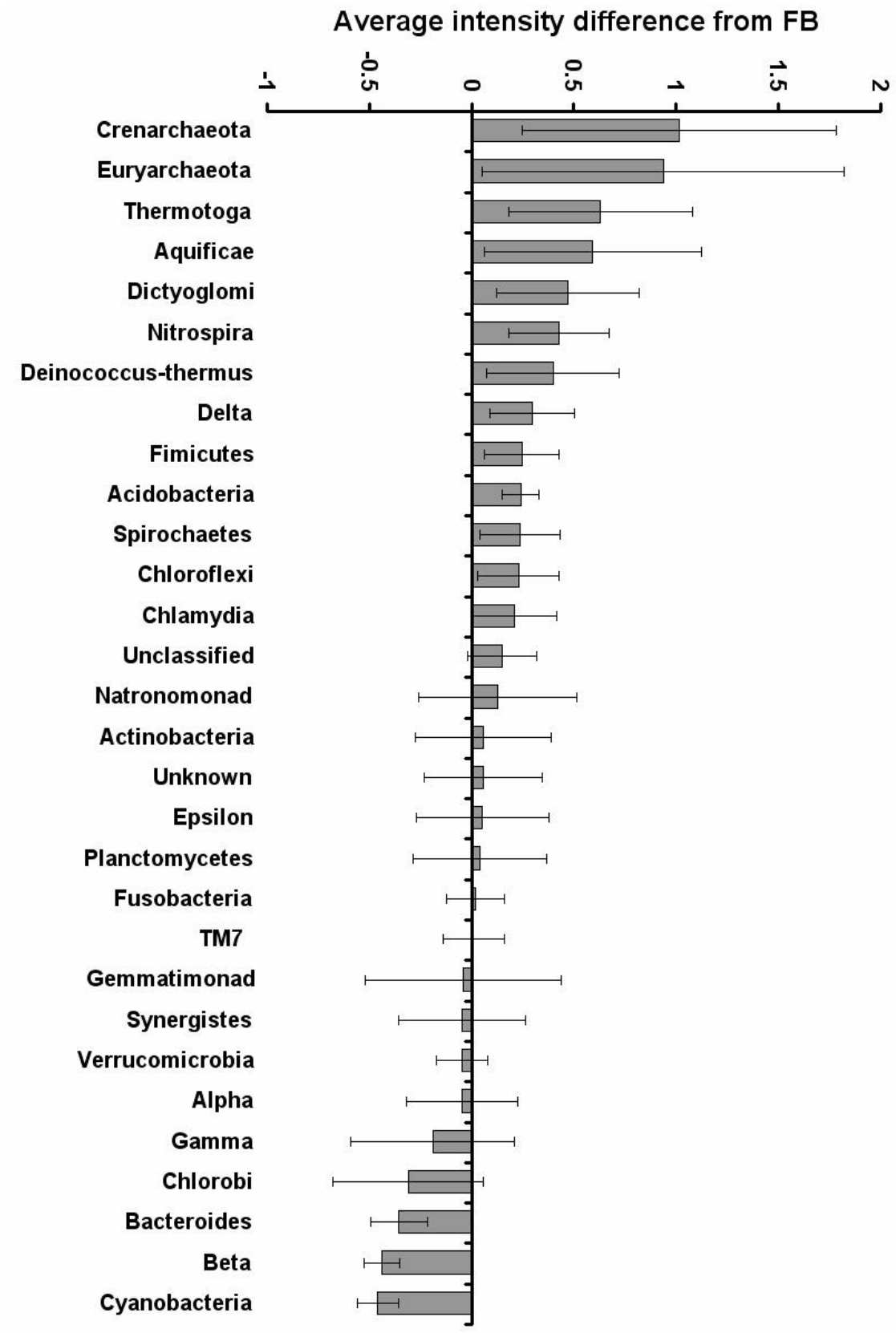
Average intensity difference from FB
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Crenarchaeota
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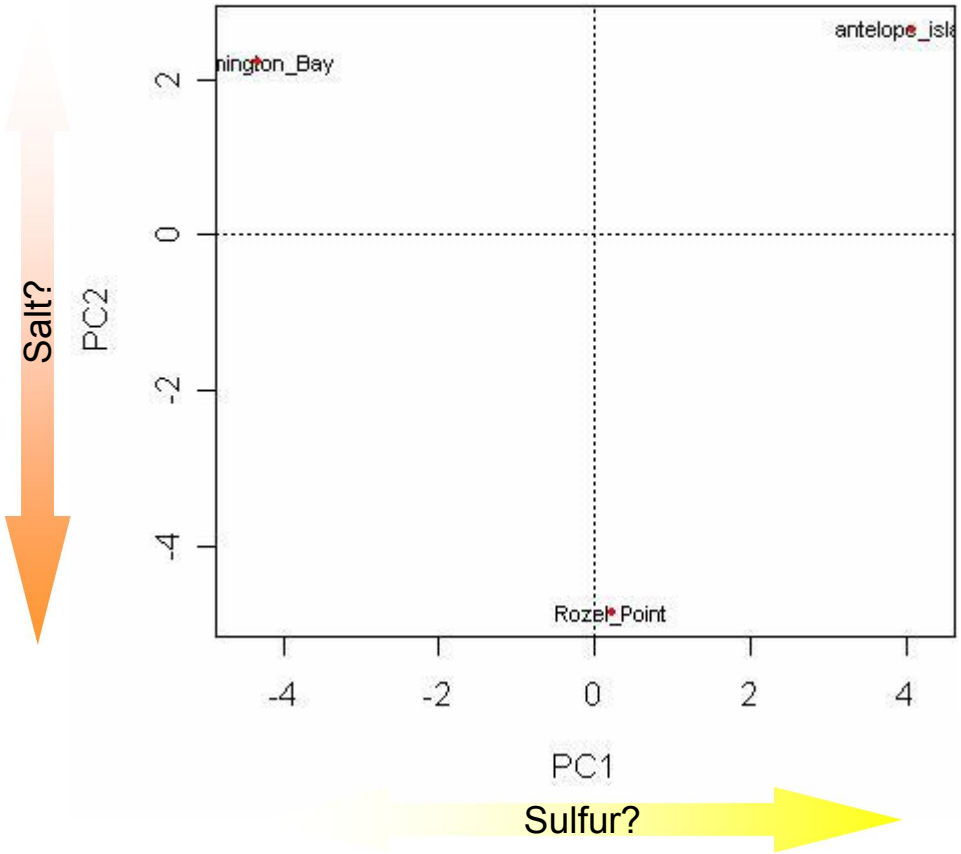
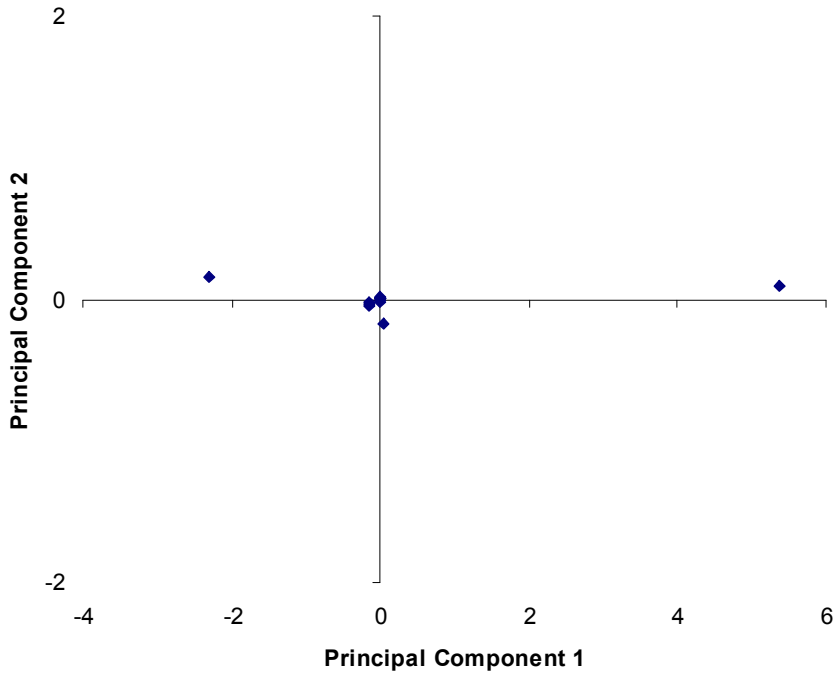
Deinococcus-thermus
Delta
Fimicutes
Acidobacteria
Spirochaetes
Chloroflexi
Chlamydia
Unclassified
Natronomonad
Actinobacteria
Unknown
Epsilon
Planctomycetes
Fusobacteria
TM7
Gemmatimonad
Synergistes
Verrucomicrobia
Alpha
Gamma
Chlorobi
Bacteroides
Beta
Cyanobacteria

Metabolites

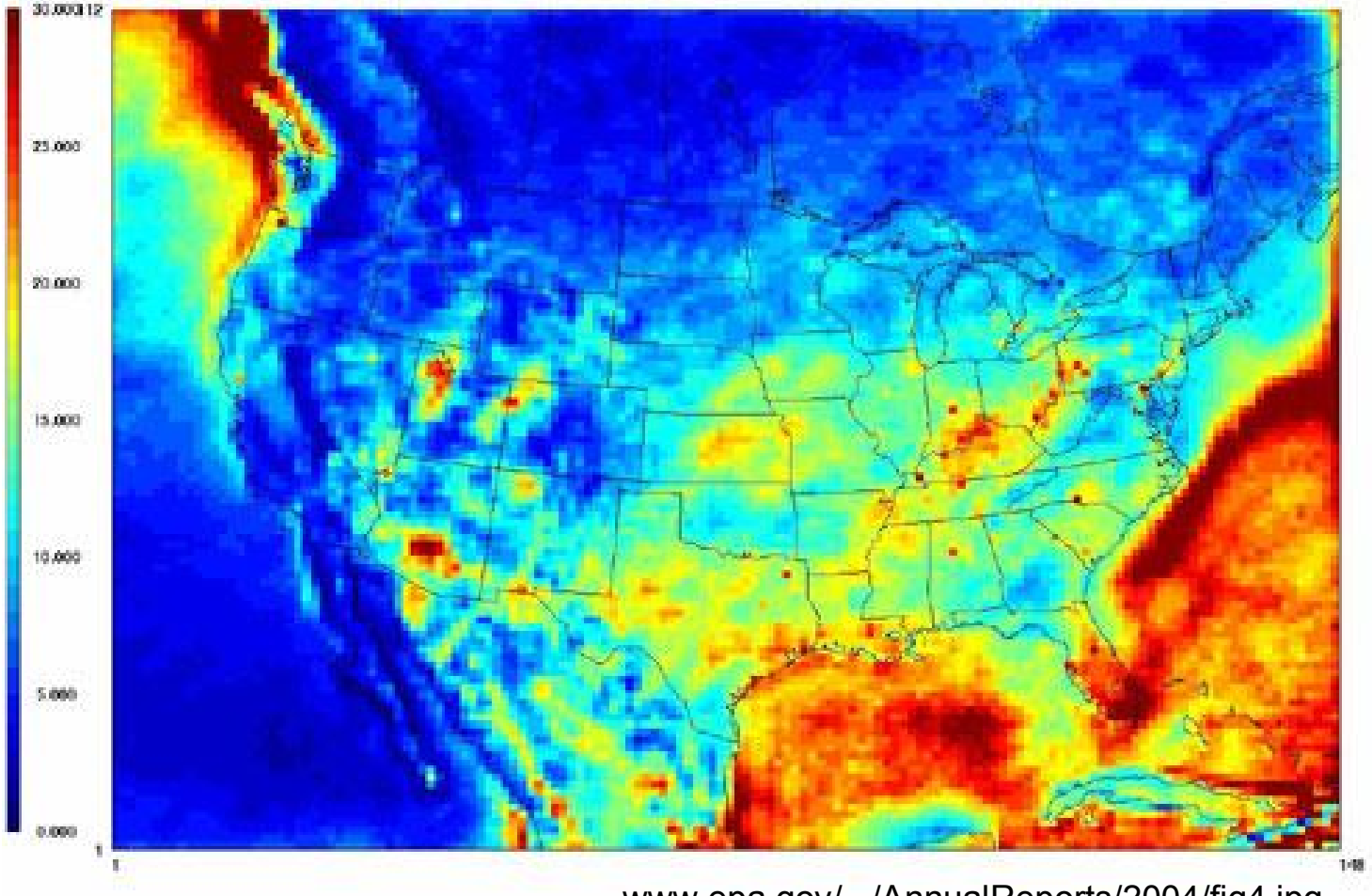
PCA of all metabolites identified



PCA of sulfur metabolites identified



Mercury



www.epa.gov/.../AnnualReports/2004/fig4.jpg

Bioaccumulation of Methylmercury

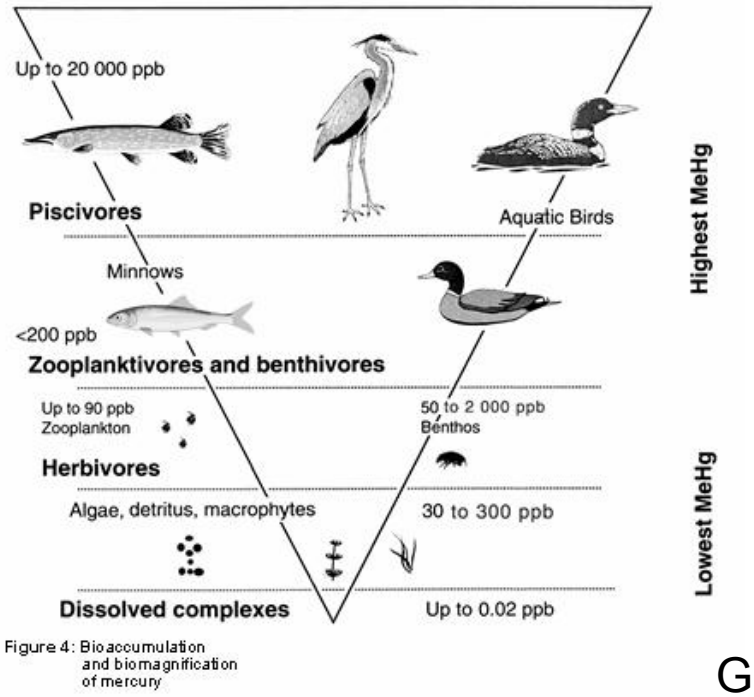


Figure 4: Bioaccumulation and biomagnification of mercury

www.ec.gc.ca

GSL = 0.05 ppb

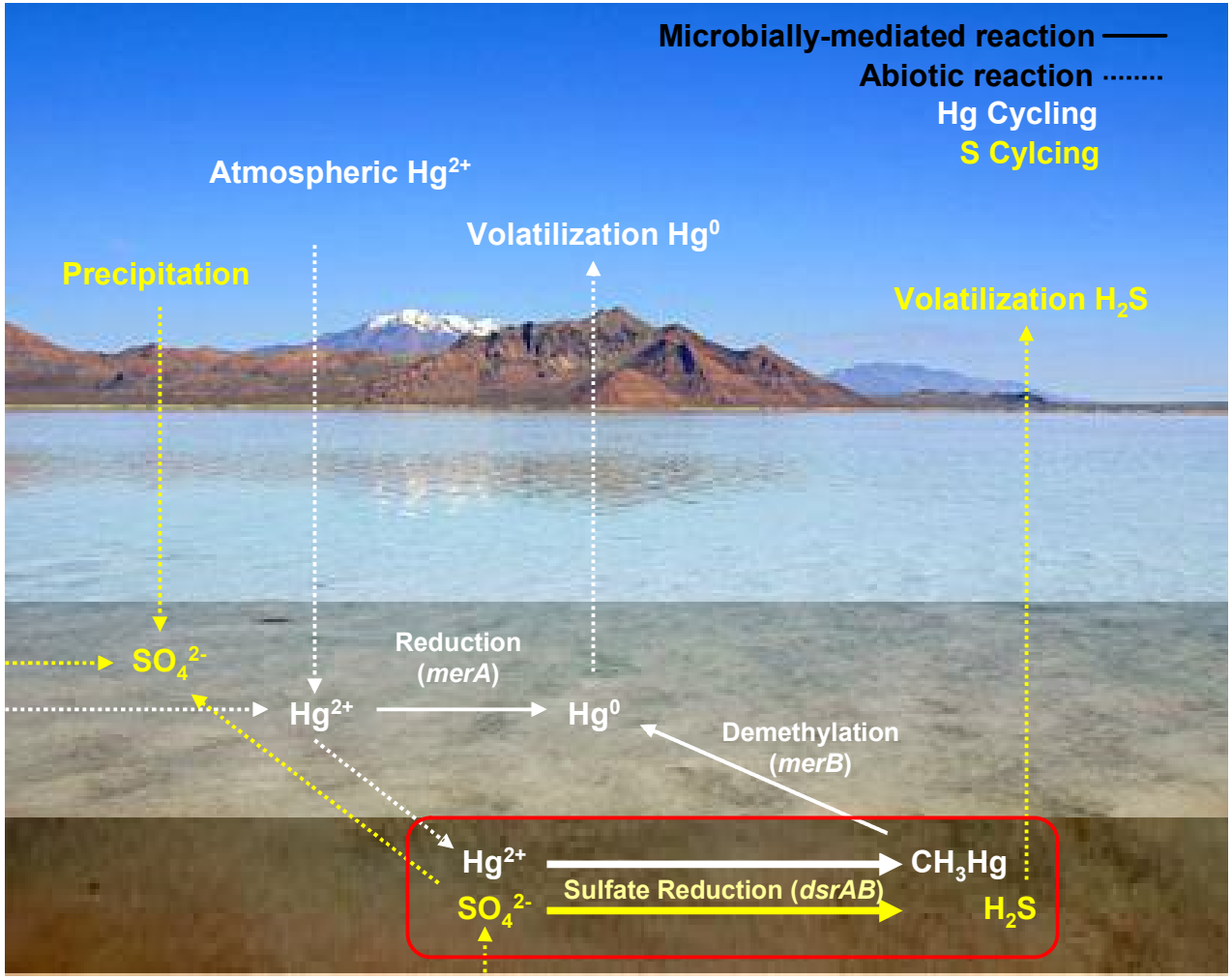
Mercury Methylation

- A strong inverse relationship between the salinity and mercury methylation.
  - Olson and Cooper, 1974

- Sediments from a 2.4% salt environment inhibited mercury methylation by ~60% of the level observed in lower-salinity sediments
  - Compeau and Bartha, 1987

- The percent of mercury as MeHg differs between fresh marsh (3.0% MeHg/total Hg) and salt marsh (1.7% MeHg/total Hg) sediments.
  - Kongchum *et al.,* 2005

Mercury and Sulfur Cycles

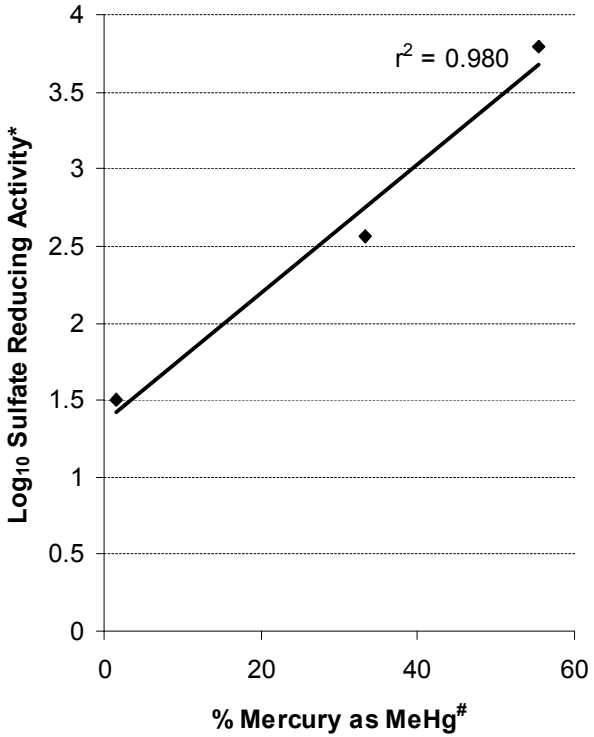


Methylation and SR factors

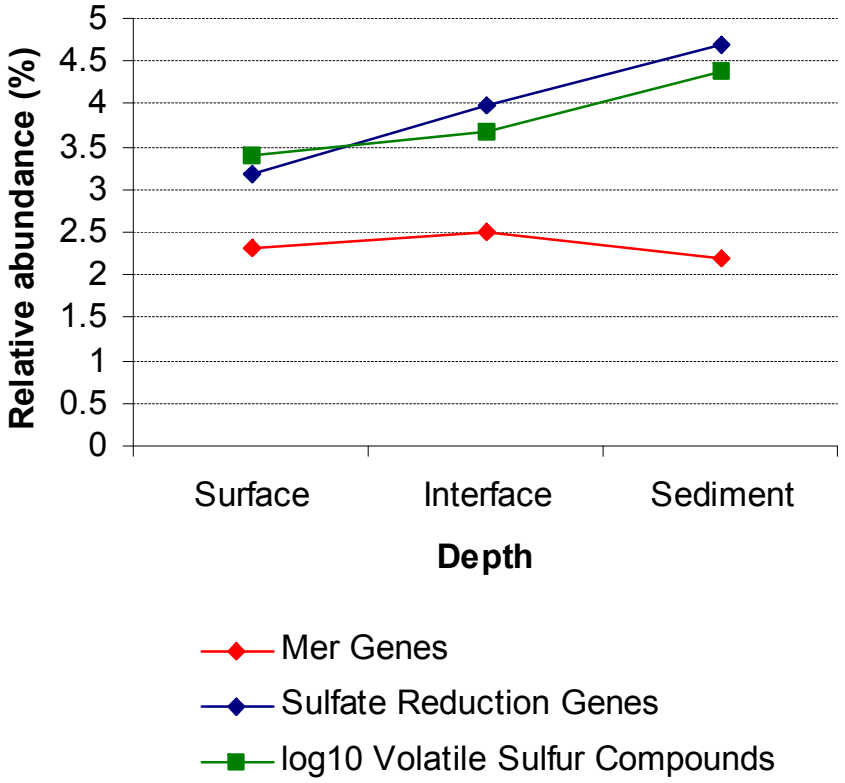
Physical or Chemical Condition*	**Influence on Methylation***
Low dissolved oxygen	Increased methylation
Lower pH	Increased methylation
Increases dissolved organic carbon (DOC)	Increased methylation
Increased salinity	Decreased methylation
Increased nutrient concentrations	Increased methylation
Increased selenium concentrations	Decreased methylation
Increased temperature	Increased methylation
Increased sulfate concentrations	Increased methylation
Increased sulfide concentrations	Increased methylation

***See U.S. EPA-OSW Human Health Risk Assessment Protocol.**

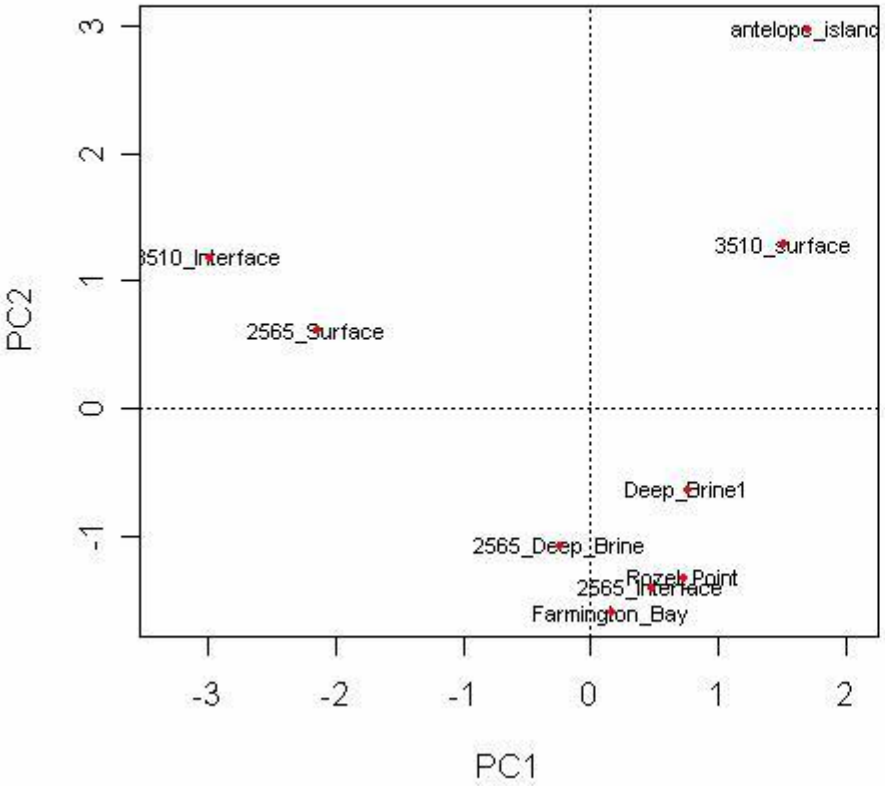
Sulfate Reduction & Methylmercury



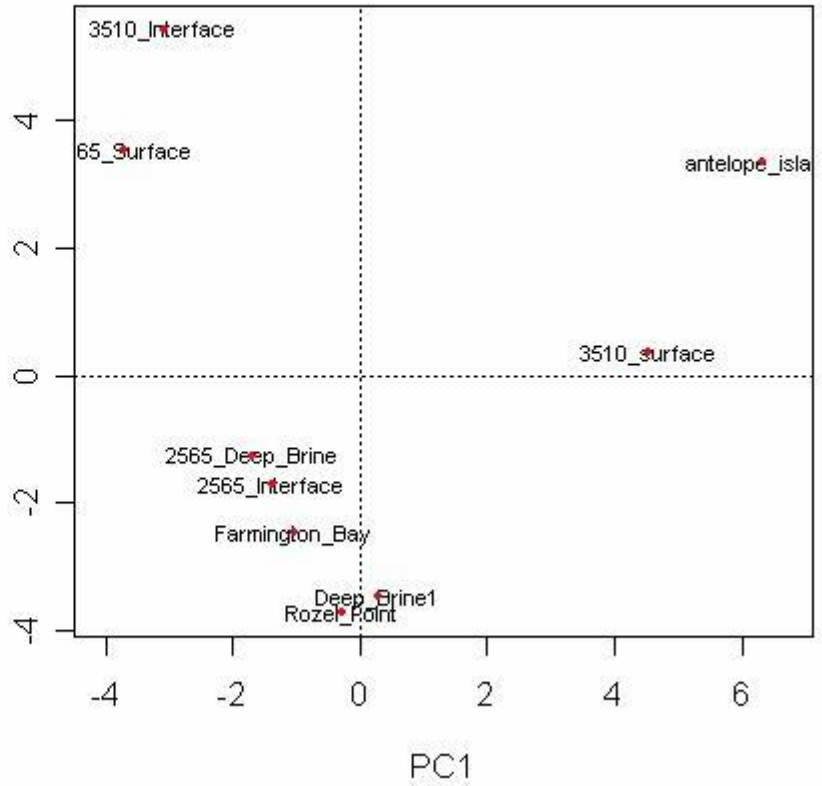
*From Brandt, *et al.,* Microb Ecol. 41:1-11 2001.
#From Naftz, *et al.,* Unpublished



Functional Gene PCA

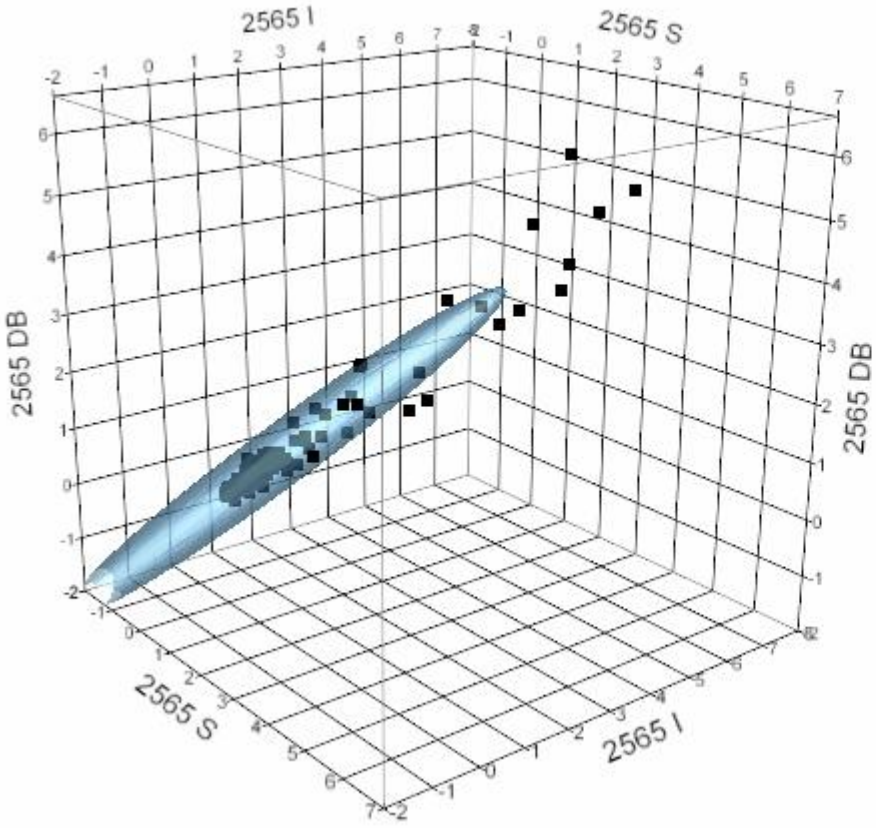


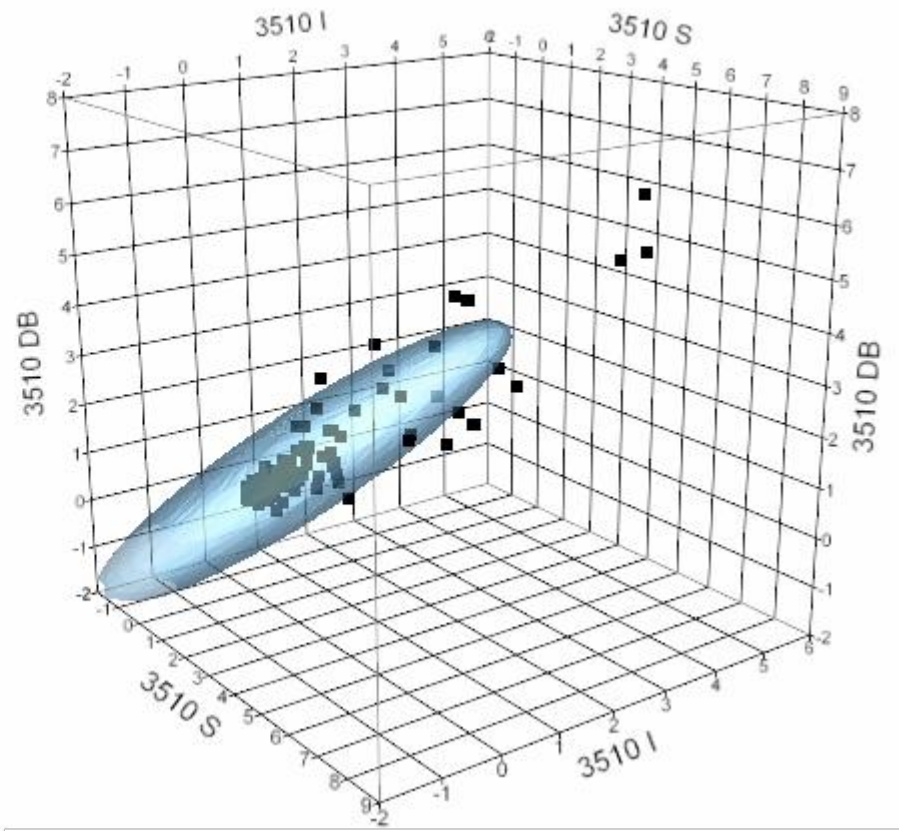
Sulfate Reduction Genes



Metal Resistance Genes

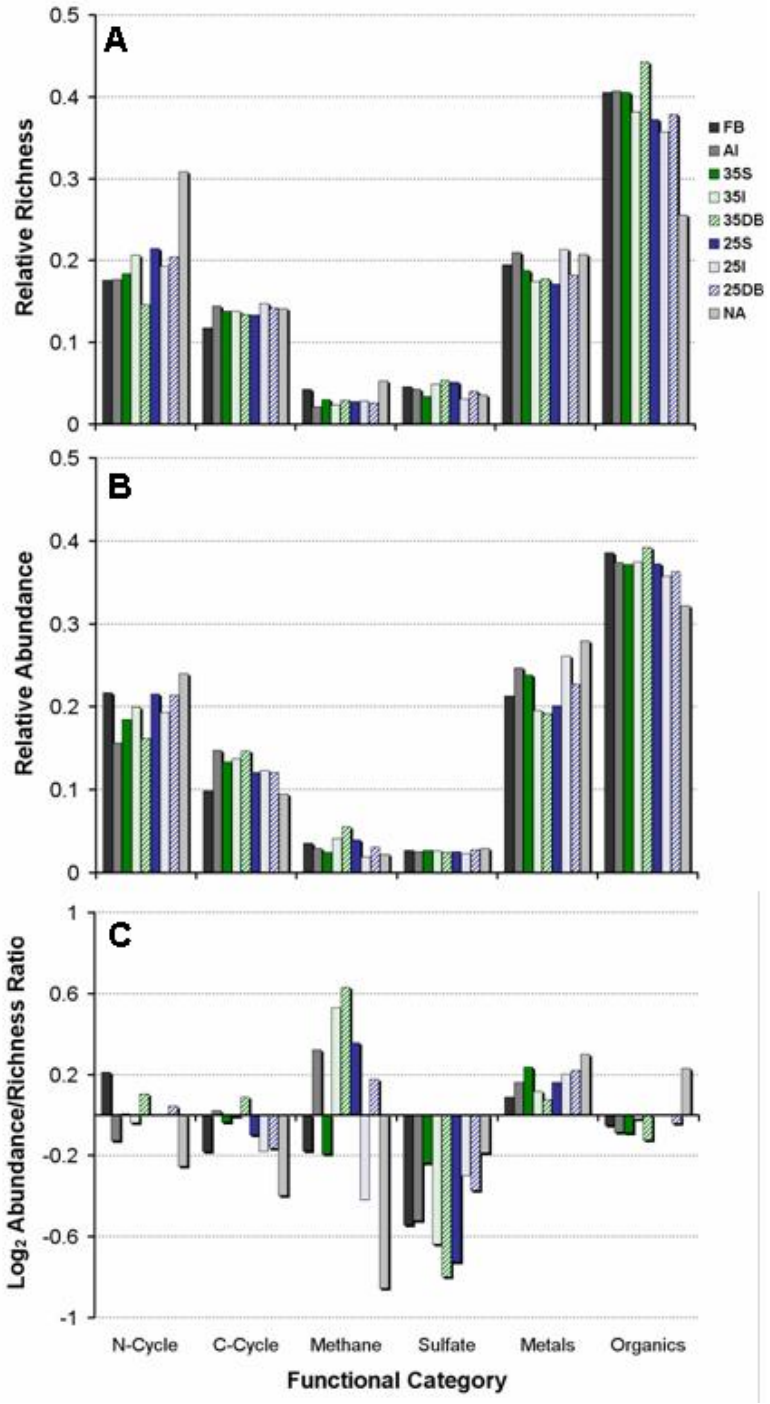
GeoChip Data





GeoChip Data

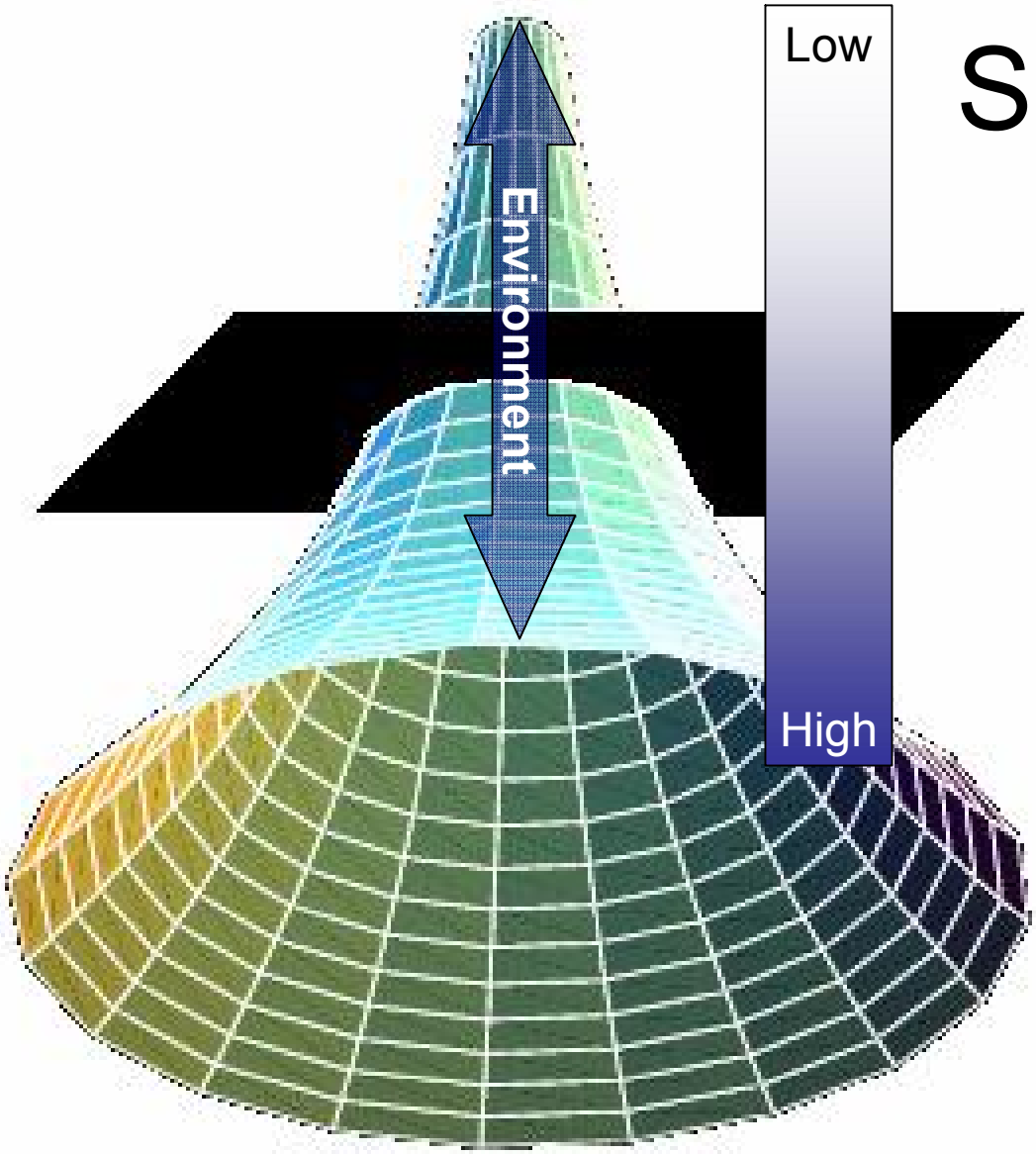
Gene Category	Relative intensity value								
	RP	AI	FB	2565 DB	2565 I	2565 S	3510 DB	3510 I	3510 S
Protocatechuate	3.33	2.41	2.97	3.67	2.71	3.14	4.04	2.86	2.37
Tellurium	3.38	2.32	3.59	3.19	4.52	3.05	0.95	3.72	1.50
Mercury	**6.43**	**3.51**	**1.63**	**3.07**	**3.99**	**3.09**	**2.07**	**2.18**	**4.22**
Sulfate Reduction	**1.41**	**1.36**	**1.42**	**1.99**	**1.13**	**2.18**	**2.39**	**2.23**	**1.17**
Chromium	9.16	1.67	5.27	5.73	5.41	3.36	1.79	2.93	1.53
Cellulase	2.77	5.61	3.24	4.19	4.67	4.11	6.25	4.61	5.57
Arsenic	4.51	4.72	3.82	3.59	5.05	3.60	5.54	3.24	6.98
Nitrate Reductase	6.04	1.73	4.82	4.96	3.73	4.16	2.48	3.56	2.66



Number of gene variants in each pathway

Abundance of gene variants in each pathway

Ratio indicates selective pressure

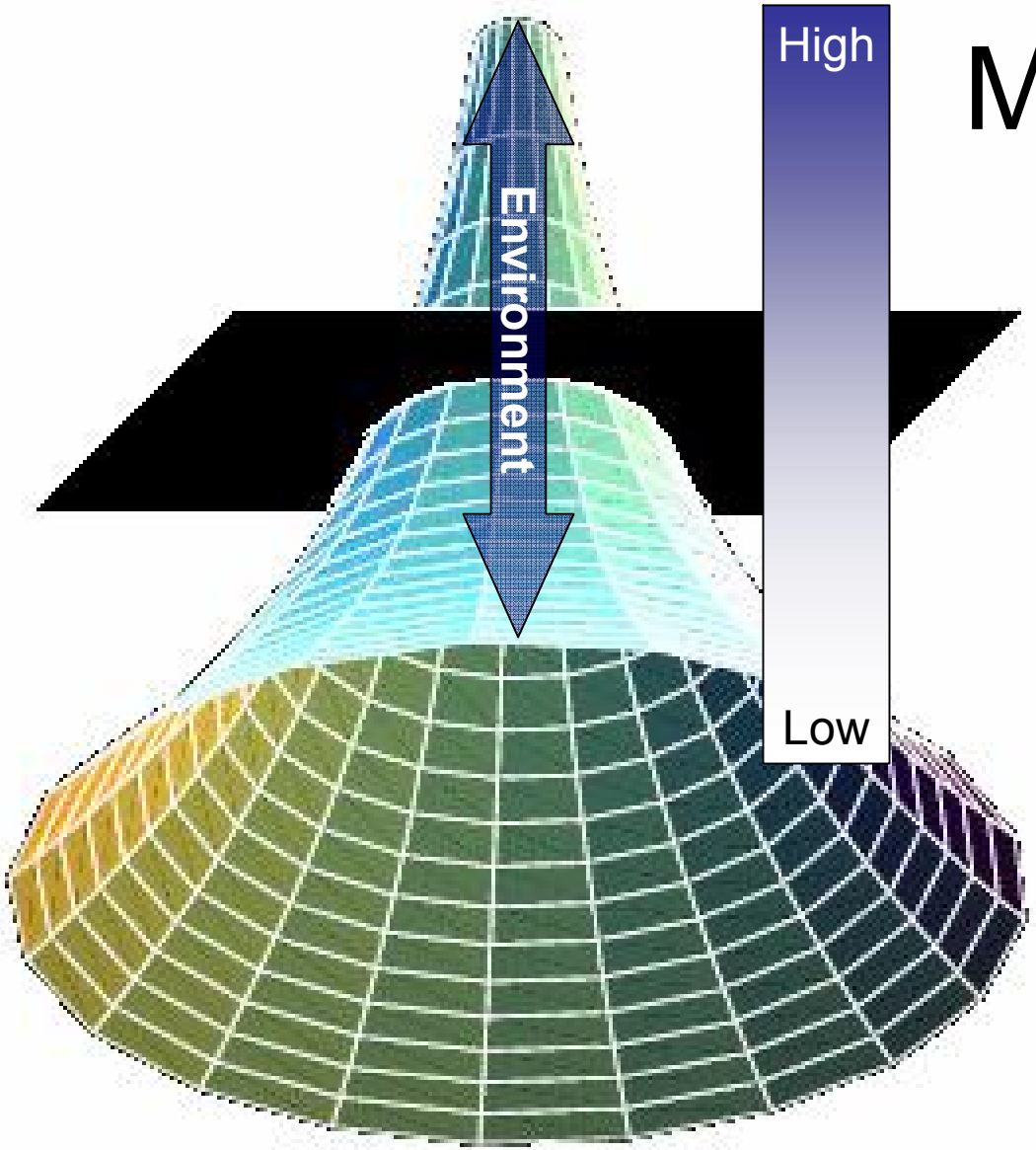


Sulfate:

dsrAB responsible for sulfate reduction

GSL has [$SO_4^=$] ranging from 10-20 g/L (extremely high)

No selective pressure for more efficient *dsrAB* genes



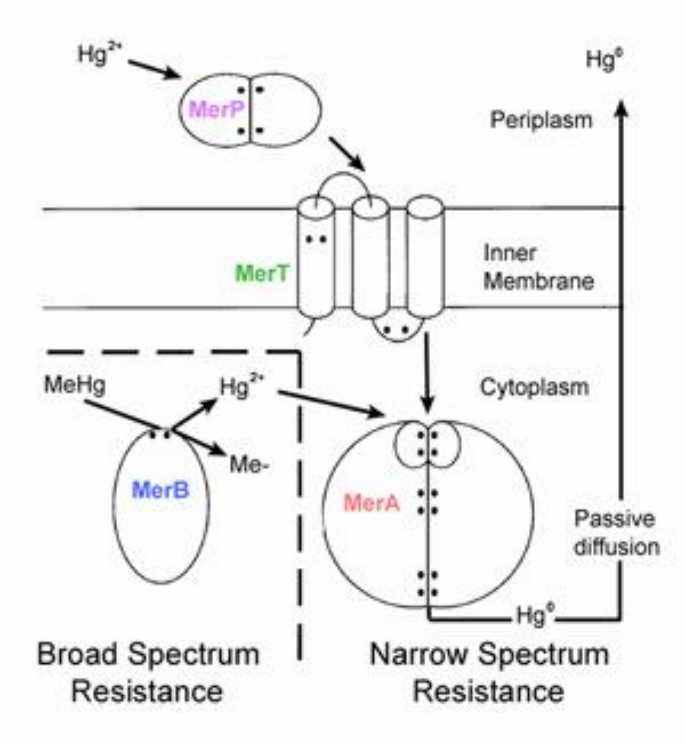
Metals:

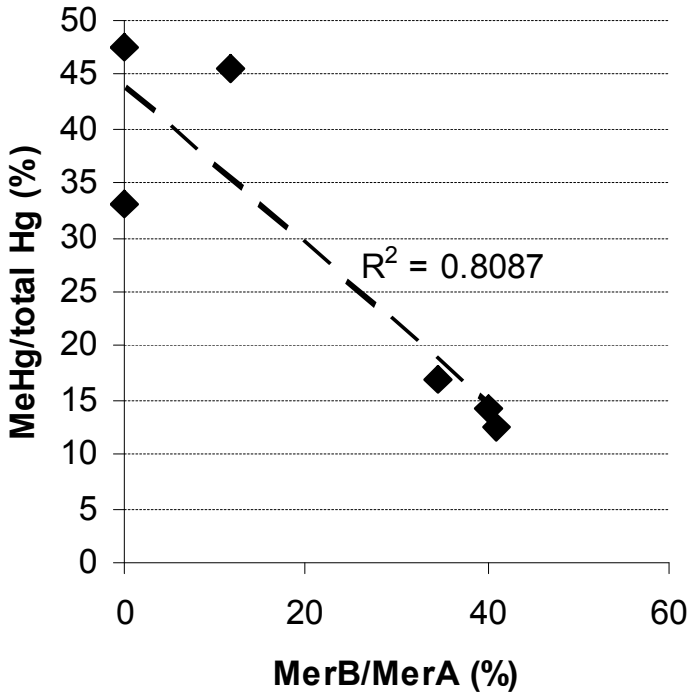
Genes are responsible for resistance to metal toxicity

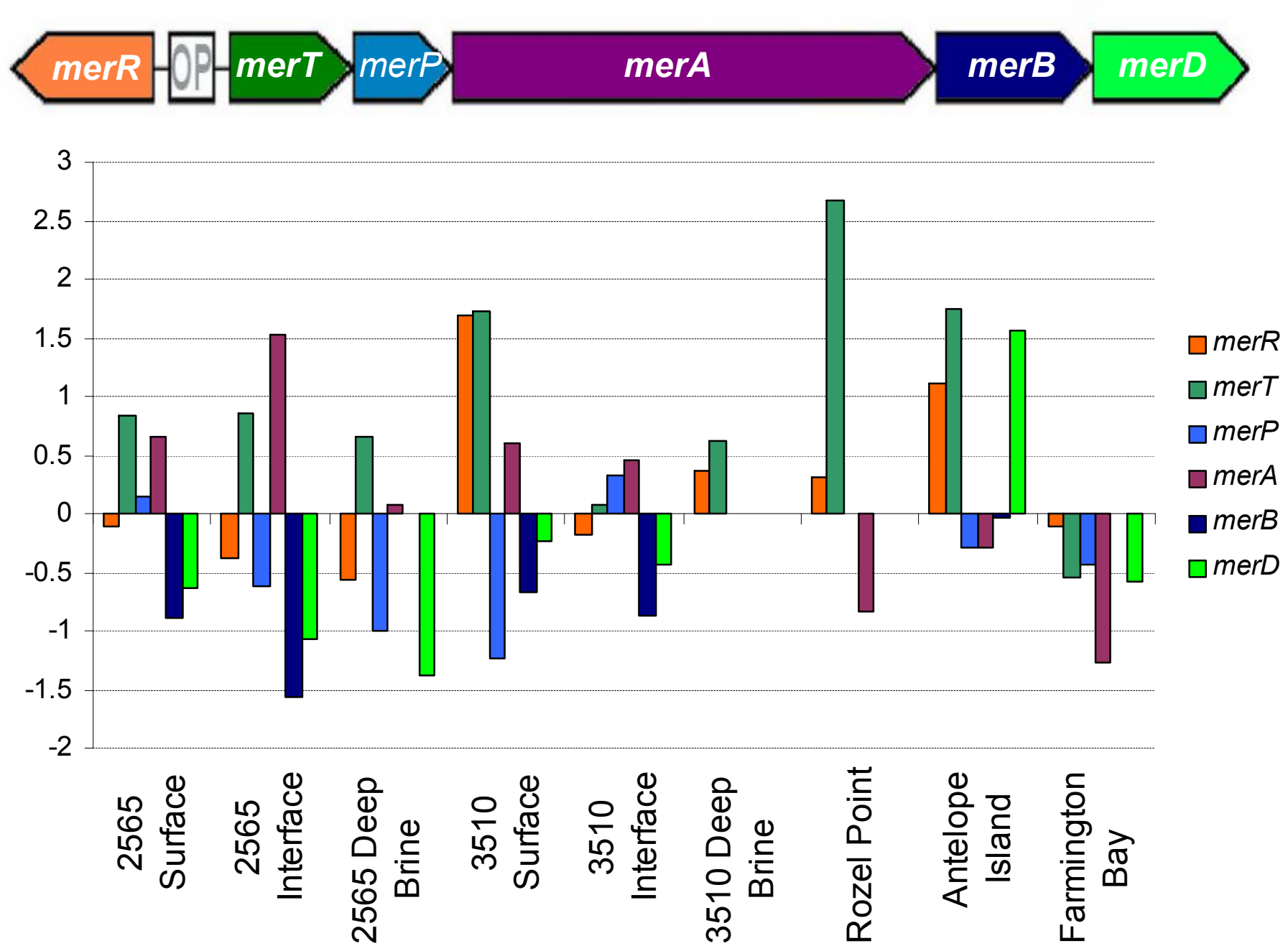
GSL has extremely high concentrations of heavy metals

Strong selective pressure for more efficient metal resistance genes

Mercury Reductase



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2565 Interface
2565 Deep Brine
3510 Surface
3510 Interface
3510 Deep Brine
Rozel Point
Antelope Island
Farmington Bay
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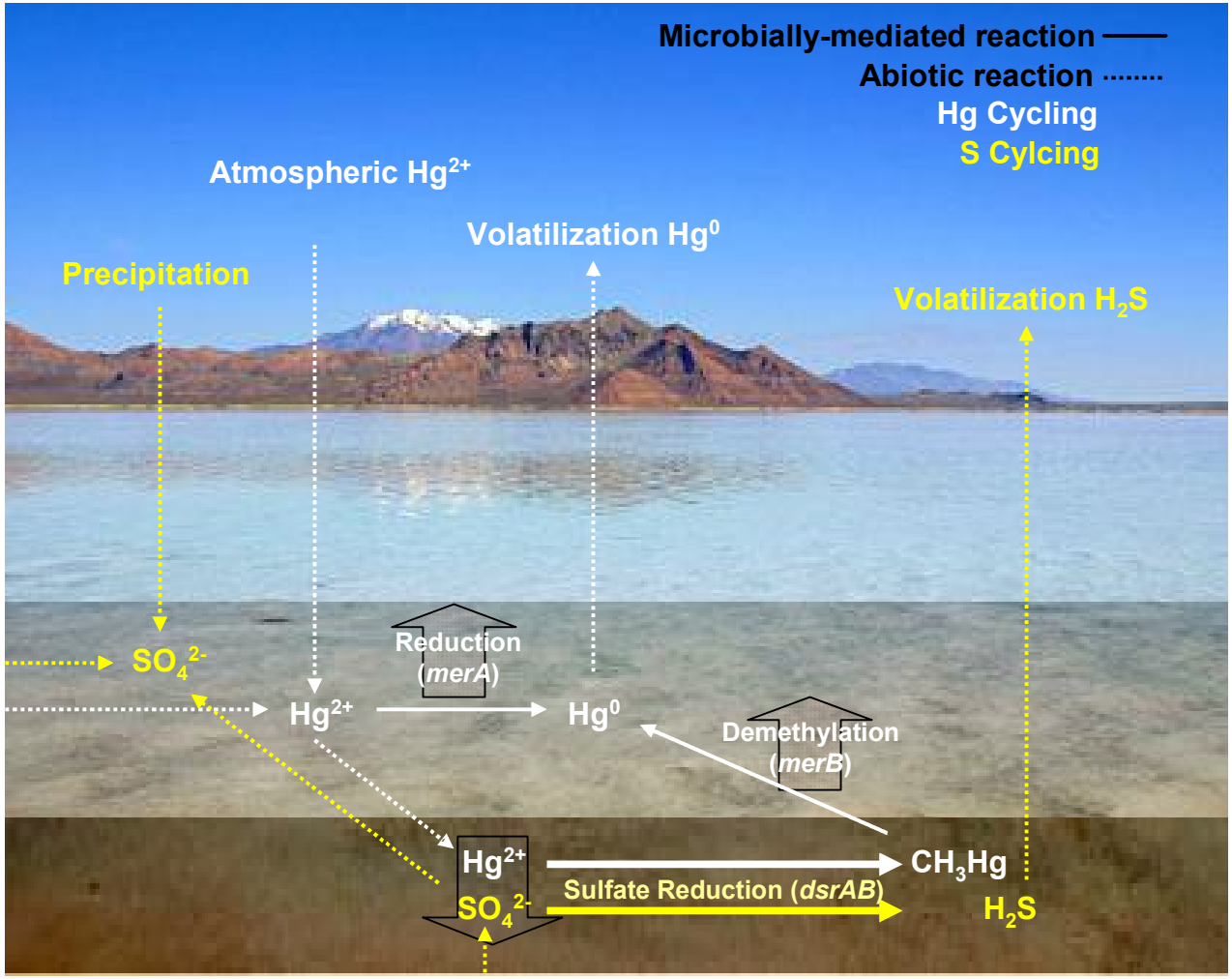
Methylmercury



Conclusions

- Highest methylmercury concentrations the USGS has ever found (Naftz)
- Sulfate reduction rates among the highest ever reported for natural environments (Brandt, *et al.,* 2001)
- Despite high salinity, mercury methylation is driven by sulfate-reducing bacteria
- Drop in methylmercury concentration coincides with demethylation genes

Acknowledgements

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